

## Long-term Qualitative Changes in Fish Populations and Aquatic Habitat in San Mateo Creek Lagoon, Northern San Diego County, California

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**Abstract.**—Patterns of abundance were documented for 17 species of fish in the lagoon at the mouth of San Mateo Creek, northern San Diego County, California from occasional observations (1974–1997) and multiple samples per year (1998–2008). Fish populations varied with Mediterranean climate patterns of rainfall, stream flow and consequent breaching of the lagoon to the ocean through the barrier sand berm. Two near-record rainfall seasons occurred during this period; the 1997–1998 El Niño due to southern storms and the 2004–2005 winter wet season of more usual storms from the north and northwest. The lagoon stabilized as fresh to brackish in the dry season and for multiple years during successive drier winters. Closed conditions benefitted the native, federally endangered southern tidewater goby, *Eucyclogobius kristinae*, but were less suitable for other native estuarine species more common in wetter years. Wet year flows also reduced non-native freshwater species; some thrived and increased predation pressure on the southern tidewater goby. Historically these exotics were absent and two additional native species were present, partially armored threespine stickleback, *Gasterosteus aculeatus*, and the federally endangered southern steelhead, *Oncorhynchus mykiss*. Restoring and maintaining a full suite of native species will require a combination of 1) habitat maintenance and restoration, 2) control or management of non-native species, and 3) reintroduction of some native fishes and amphibians.

Estuarine fish community studies exist for many California estuaries naturally or artificially open to the ocean on a year around basis (Allen et al. 2006). Most of these larger estuaries historically closed seasonally (Warne et al. 1977; Fong and Kennison 2010). Only a few studies exist for California systems still opening and closing in some approximation of the original Mediterranean climate-influenced hydrological cycles such as Ambrose and Meffert (1999) for Malibu Lagoon, Los Angeles County and Collins and Melak (2014) for Devereaux Slough, Santa Barbara County. Even then fish population composition and structure probably differ from the historical or original patterns (Lane 1977; Swift et al. 1989; USFWS 2005). Some native species have been extirpated from these systems and

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other non-native species have become established. San Mateo Creek Lagoon in coastal southern California and many smaller lagoons and estuaries still function in similar fashion to the original or historic hydrological patterns and provide insight to historical fish populations and their seasonal cycles. The addition of non-native species also provides insights to their interactions with, and effects on, the native fauna.

The number and composition of the native and non-native fishes fluctuates with the amount of freshwater inflow and degree of salt water invasion. These changes were documented to varying degrees from 1975 to 2008 in San Mateo Creek Lagoon in northern San Diego County, southern California and most intensively from 1996 to 2008. Collections were primarily to monitor the federally endangered southern tidewater goby, *Eucyclogobius kristinae* [then not separated from the northern species, *E. newberryi* (Swift et al. 2016)], and to remove invasive species. Other recent and historical records and observations added additional information. The objectives of this paper are to describe the fish community of San Mateo Lagoon and to document: 1) the seasonal and year-to-year fluctuations in abundance of the fishes (and a few associated aquatic organisms); 2) the interactions of native and non-native fishes; 3) assess the success of re-introduction of southern tidewater goby; and 4) provide management recommendations for restoration of the coastal lagoon habitat for native fishes.

### Description of the Area

San Mateo Creek formed a small, narrow lagoon (wetted surface 1-4 ha) in northern San Diego County, California just south of the Orange County line (Fig. 1) and on the north edge of Marine Corps Base Camp Pendleton (MCB). It lies in San Onofre State Beach managed for recreation and habitat preservation by the San Onofre Unit of California State Park system. Emergent vegetation usually bordered the lagoon except for the sand berm at the mouth. After a few dry years even the berm became vegetated on the inland lagoon margin. Over 90% of the margin of the lagoon had tules (*Scirpus sp.*) or cattails (*Typha sp.*) with water cress or other emergent herbaceous plants near the shallower upper end. At higher water levels the lagoon invaded upstream into the riparian willow and cottonwood forest to or near the "Old Road Bridge" just downstream of the current Interstate 5 bridge (Fig. 1). As the lagoon warmed in the spring and water exceeded about 15° C in April or May, widgeon grass, *Ruppia*, and filamentous green algae began to regrow and filled much of the open water of the lagoon by fall. Some green algae floated, and onshore breezes pushed it inland to form spongy mats 2.5-7.5 cm thick covering the upper one-third to one-half of the lagoon by late summer or fall. Both the widgeon grass and green algae also were reduced in the fall and winter by cooler temperatures and grazing water fowl, mostly coots (*Fulica americana*). In the wet years some of these aquatic plants were scoured away by high flows.

In March 1998 strong El Niño storm flows and earth moving activities in the lagoon removed virtually all the marginal vegetation. The lagoon margin became partially re-vegetated as the season progressed and emergent aquatic vegetation gradually invaded into the lagoon over the next few years (Figs. 2-6). During the almost equally wet 2004-2005 winter season the rainfall and high stream flows were more evenly distributed, no excavation was performed, and marginal vegetation largely remained. The March 1998 El Niño flows also partially filled the lagoon with sediment reducing wetted area to 1-2 ha restricted to the seaward end of the lagoon (Fig. 2), extending 100-150 m upstream of the railroad bridge. Through subsequent years the lagoon enlarged to 3-4 ha when closed (Figs. 3-6)

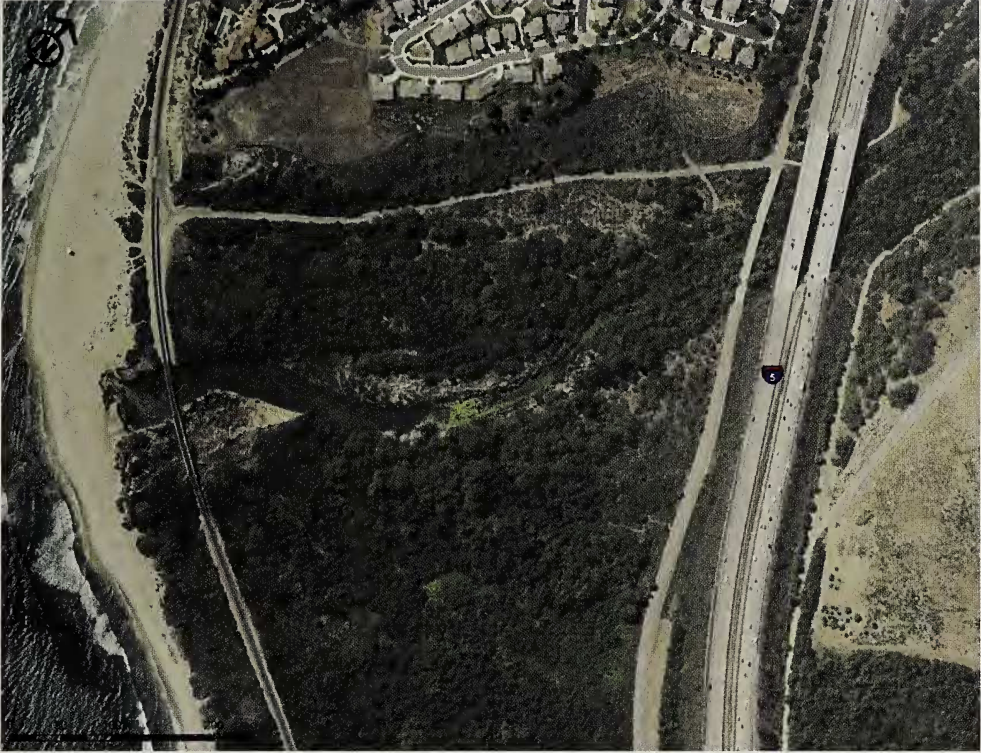


Fig. 1. Aerial view of San Mateo Lagoon in typical summer/fall closed condition, separated from the ocean by a sand berm. Perennial creek originates in dry season from upwelling from the gravel at the right edge of the photo above the multilane Interstate 5 Freeway. The smaller two-lane “Old Road” bridge downstream is the earlier U. S. Hwy 1 Bridge dating from the 1930s. Figure by Edward Erwin, Brad Kelly, Merkel and Associates.

and extended 300 to 400 m above the railroad bridge. The water was up to 1.5 m deep at the lower end and gradually shallowed to the upper end. From 1998 to 2004 a deeper “hole” about 20 m in diameter and slightly more than 2 m deep was present about 100 m upstream of the railroad bridge on the north side.

Lagoon opening and closing was documented (Fig. 7) to varying degrees and was determined with direct observation and information from others working in the area. It strongly opened in early 1998 and early 2005 and 2006 and less in early 2000, 2001, and 2003. It was artificially opened to an unknown extent in January 2000 (State Parks Lifeguard, pers. comm.) and remained closed or opened only briefly in the other years. After initial opening due to high freshwater inflows along with scouring by longshore currents (Bascom 1980) the barrier sand berm rebuilt. The berm built progressively wider through the summer and fall reducing the likelihood of either ocean wave wash over or breaching and we did not observe or hear of any lagoon opening solely from surf action. At low tides low salinity water was observed seeping from the lower edges of the sand berm into the cobble habitat off the mouth of the lagoon. This seepage and evaporation was slightly higher than inflow since lagoon water level fell slowly through spring, summer, and fall as the sand barrier builds up higher and wider. In the second dry period after 2004-2005 the lagoon fell from 3-4 ha to less than 1 ha in wetted surface area by mid-2008.



Fig. 2. San Mateo Lagoon. Upper: Downstream view of lagoon from Old Road Bridge; Lower: Lagoon mouth from north. Lagoon partially open to the ocean. 11 June 1998.



Fig. 3. Upper: Downstream view of lagoon from Old Road Bridge; Lower: Lagoon mouth from north. Lagoon closing with vegetation beginning to encroach on lagoon. 14 July 1999.



Fig. 4. San Mateo Lagoon. Upper: Downstream view of lagoon from Old Road Bridge; Lower: Lagoon mouth from north. Increased vegetation and closed to the ocean. 29 June 2000.



Fig. 5. Upper: Downstream view of lagoon from Old Road Bridge; Lower: Lagoon mouth from north. Further vegetated and narrowly open. 30 March 2001.



Fig. 6. Upper: Downstream view of lagoon from Old Road Bridge; Lower: Lagoon mouth from north. Lagoon extensively vegetated and narrowly open to the ocean. 23 June 2003.

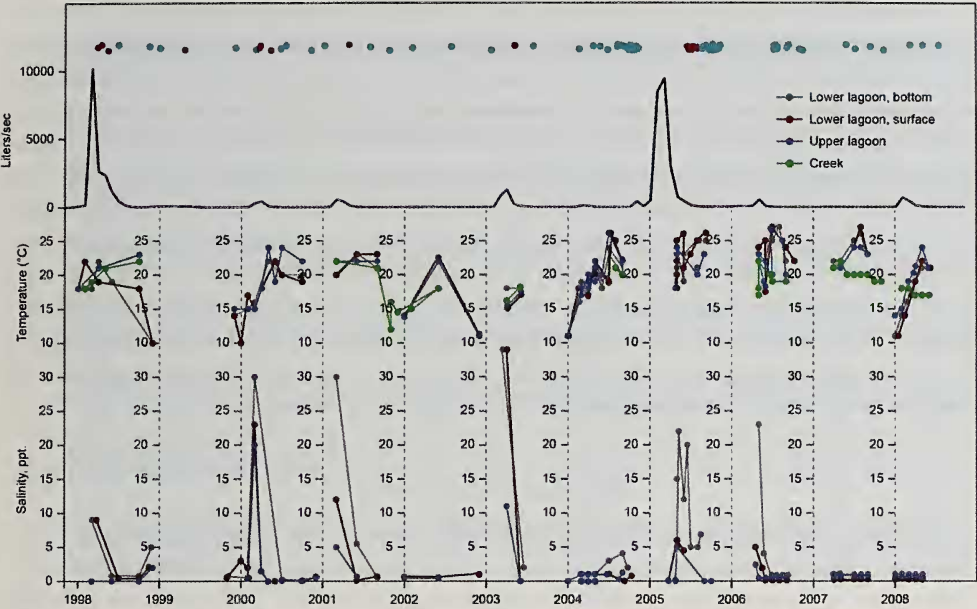


Fig. 7. Water temperature and salinity at San Mateo Creek and Lagoon, 1998-2008. See text for locations and methods of measurement. Dotted vertical lines represent January 1<sup>st</sup> of each year.

The substrate of the lagoon was over 90% sand. Some marginal pockets of finer clay or mud exist as well as scattered small stones or even gravel at the upper end near the stream mouth. After winter flows the sand was relatively unconsolidated. A 1-3 cm marl-like or flocculent layer intermixed with filamentous green algae developed over the sand as the warm season progressed. This layer persisted unless flushed out during high flow events. During summer and fall closures and winters when the lagoon failed to open, the salinity remained  $\leq 3\text{‰}$  with the deep pocket  $\leq 5\text{‰}$ . When open and while closing again over days or weeks the lower lagoon became stratified with salinities up to  $34\text{‰}$  near the bottom in the lower one third or so of the lagoon (Fig. 7). In the spring of 2005 the saline bottom layer retained some ocean or sea water derived luminescence lacking in the upper, fresher layer. The water temperature ranged from 9-11° C in mid-winter and up to the mid-20s in midsummer in most of the lagoon. In the spring the surface of the lower lagoon and shallow upstream margins warmed faster than the bottom water but by summer and fall the temperature only varied one or two degrees between top and bottom. The inlet stream was close in temperature to the lagoon in the earlier years since it was also open to solar warming. In later years riparian canopy allowed the stream to remain cooler in summer,  $\leq 21^{\circ}\text{C}$ . Small areas of the upper lagoon under floating algal mats also remained cooler than the main lagoon as at times did the shaded areas under the ends of the railroad trestle. Dissolved oxygen (DO) and pH were taken less frequently than temperature and salinity; DO was almost always  $\geq 4\text{ mg/l}$  and less a few times only at the bottom of the deeper area along the north shore about 100 m upstream of the railroad bridge. The pH was mostly between 6.4 and 9.6 except on 29 July 2004 when the values were between 4.4 and 5.9. Water was very turbid during storm flows, but the stabilized lagoon was usually clear with good visibility down to 1 m or more and became more cloudy and greenish in the warm months presumably due to the development of phytoplankton.

San Mateo Creek drains about 355 km<sup>2</sup> up to elevations of 1090 m largely on MCB and San Mateo Canyon Wilderness of the U. S. Forest Service in the Santa Margarita Mountains. It has no major impoundments or dams and few small residential or agricultural ponds on a few tributary canyons. Creek flow varied widely and was at or near record highs twice; the 1997-1998 El Niño year and the 2004-2005 rainfall year (Fig. 7, top). In contrast the years of 1998-1999, 2001-2002, and 2003-2004 were years of exceptionally low rainfall. The surface flow dried in the lower 7-8 km of creek except for a small perennial flow of 28-56 liters/sec into the upper lagoon, upwelling in the stream bottom about 150 m upstream of the northbound Interstate 5 bridge. In February 2002 up to 3785 l/day were added to the stream from dewatering related to construction on the Interstate 5 bridge. Sections of perennial flow existed in mountainous headwaters 8-15 km upstream (Hovey 2004; Swift, Holland, pers. obs.). The lower 7-8 km of alluvial valley absorbed the first winter rains and continuous surface flow took multiple storm events.

### Materials and Methods

Sampling objectives were: 1) presence-absence surveys and monitoring of the federally endangered southern tidewater goby, *Eucyclogobius kristinae* (1991, 1993, 1996, 1998-2008); and, 2) removal of non-native predators considered threats to populations of the native fishes, amphibians and reptiles (1998-2000; 2004-2008). Sampling was conducted with seines 3.2 X 1.2 and 5 X 1.8 m with 3 mm square knotless mesh with 28.35 g weights every 15 cm, and 9.1 X 1.8 m, 9 mm square mesh similarly weighted. Non-native fishes, amphibians, and crayfish were also targeted with frog gigs (spears), Gee's minnow and crayfish traps, and larger fyke nets. More visits and seine hauls were taken in 1998-2003 to monitor presence/absence of tidewater goby, and in 2004 to 2008 to remove non-native fish (Appendix I), crayfish (*Procambarus clarki*), bullfrog (*Rana catesbeiana*) larvae (tadpoles) and non-native turtles. Fishes were identified and counted in the field, larger numbers  $\geq 50$  sometimes were estimated to avoid stressing native species. Native fish, amphibians, and reptiles were released at the site of capture and exotics were removed. Swift was present for virtually all sampling; voucher specimens were deposited in the Section of Fishes, Natural History Museum of Los Angeles County (LACM) and genetic vouchers of southern tidewater goby in the Jacobs Laboratory, University of California, Los Angeles. The catch data in the Appendix I are based on the seine hauls, 4 to 49 (average 24.2) per visit usually distributed over two thirds or more of lagoon. Length and width of seine hauls was recorded and catch-per-unit-effort (CPUE) was calculated by dividing the number of fish caught by total area seined. The mesh of the larger seines, 9 X 9 mm square (81 mm<sup>2</sup>) was considered nine times more likely to allow small species to pass through than the smaller 3 X 3 mm square (9 mm<sup>2</sup>) mesh. For calculation of CPUE for the two common small species, southern tidewater goby and mosquitofish, the catch data for larger mesh nets (Appendix I) were multiplied by nine for the graphs. The more frequent samples in 2004-2006 were grouped by month for calculation of CPUE. Hierarchical cluster analyses with complete linkage were performed for six scenarios, namely utilizing all species for the time period 1998-2008, and for two subsets, each including a strong wet year and the subsequent drier ones, 1998-2003 and 2004-2008. Three additional analyses utilized these same time periods with a subset of the 12 most common species. Water quality (temperature, salinity, pH, dissolved oxygen, and turbidity) was taken at the surface and bottom in water  $\geq 1$  m deep with an Horiba U-10 water quality instrument; in shallower water one sample was taken at mid-depth. Often only temperature and salinity were taken with a hand-held thermometer

and refractometer, respectively. These were taken in mid to late afternoon at three to six representative locations around the lagoon before seining mixed the water column. During periods of lagoon closure water quality data were taken intermittently since lagoon conditions changed very little over weeks or months. The lower lagoon data were in the deepest portion of the lagoon seaward of the railroad trestle and the upper lagoon varied from 100-150 to 350-400 m above the lagoon depending on water levels. Only water temperature was taken in the creek. Stream flow data for San Mateo Creek was from the USGS Web Interface for Gauging Station (USGS 11046300, San Mateo Creek near San Clemente), about 7 km upstream of the ocean. Fish sampling was done less frequently in the tributary creek above the lagoon but usually at least once in months sampling was done. On 26-27 November 2001 a stream diversion for bridge construction isolated 113 m of the creek centered on the Interstate 5 bridge and all native fish were removed and placed in the lagoon. On 8 February 2002 a similar effort was undertaken on 93 m of the previously established channel. The stream was 1-4 m wide, to 60 cm deep, with an estimated average depth of 10 cm, flow of  $\leq 56$  l/sec.

### Results

The dates, number of seine hauls, areas seined, species, and catch numbers are presented in the Appendix I. Seine hauls captured 53,435 fishes among seventeen species and 92% of the fishes captured were southern tidewater goby (22,478; 42%) and mosquitofish, *Gambusia affinis* (26,966; 50%). Three other species were over 1%, namely black bullhead, *Ameiurus melas* (1096; 2.0%), deepbody anchovy, *Anchoa compressa* (922; 1.7%) and green sunfish, *Lepomis cyanellus* (796; 1.5%) and the remaining species under 1% each; striped mullet, *Mugil cephalus* (264), slough anchovy, *Anchoa delicatissima* (261), grunion, *Leuresthes tenuis* (246), staghorn sculpin, *Leptocottus armatus* (140), largemouth bass, *Micropterus salmoides* (122), topsmelt, *Atherinops affinis* (62), California killifish, *Fundulus parvipinnis* (51), arrow goby, *Clevelandia ios* (14), reef surfperch, *Micrometrus aurora* (8), yellowfin goby, *Acanthogobius flavimanus* (6), longjaw mudsucker, *Gillichthys mirabilis* (2), and bluegill, *Lepomis macrochirus* (1). On 11 April 2007 a small goldfish, *Carassius auratus*, about 3.8 cm was speared in the lagoon while searching for bullfrogs. After March 1998 high stream flows and earth-moving efforts to protect the railroad bridge southern tidewater goby were not detected for two years, presumed extirpated, and 520 were introduced from San Onofre Lagoon on 7 January 2000.

Number of species (richness) was highest during and within weeks to months of lagoon opening or breaching during wet years (Appendix I). The actual numbers of fish caught was lower during these periods and highest during intermediate low rainfall years when the lagoon did not open or only opened briefly, for a few days or weeks. During dry seasons or successive dry years in the fresh or nearly fresh lagoon populations of the two overwhelmingly dominant species, the native southern tidewater goby and non-native mosquitofish increased. These two species were almost continuously present except that the tidewater goby was extirpated twice during the study, and likely a third time historically in the early 1980s as discussed below. The goby was not detected on two occasions in early 2000 probably because of the small number introduced were likely decimated by the artificial opening of the lagoon noted above. They began to reproduce later and rose to large numbers later in 2000 reflecting an expanding population. A similar increase occurred in 2005 when high flows reduced the gobies and they increased later in the year.

The numbers of both native and non-native fishes usually increased during the warm months and usually declined in the cool months (Figs. 8 and 9). During wet years this

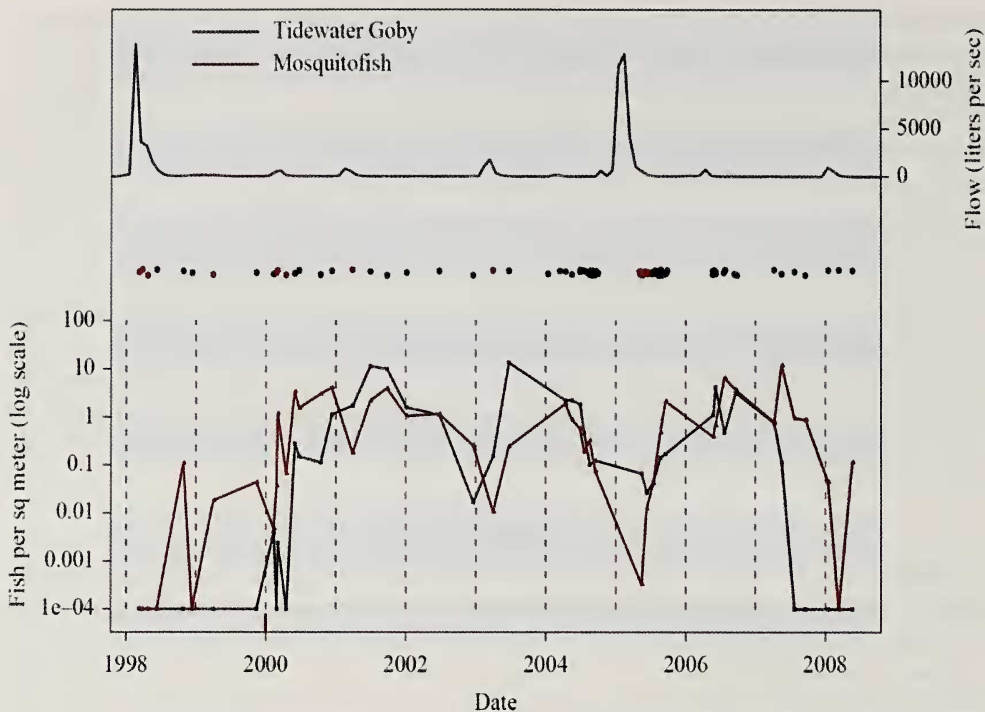


Fig. 8. Abundance of southern tidewater goby and mosquitofish, the two overwhelmingly common species in San Mateo Lagoon, 1998-2008. Catch data from Appendix I was multiplied by the indicated multiplier and plotted on a log scale. Dotted vertical lines represent January 1<sup>st</sup> of each year.

increase was partly due to reproduction by topsmelt and anchovies as well as Tidewater Gobies and Mosquitofish. During dry years when the lagoon remained fresh or brackish, the increase in southern tidewater gobies and mosquitofish was augmented by smaller increases in Green Sunfish and Black Bullhead, particularly after the 2004-2005 wet season.

The native estuarine fish species, topsmelt, slough anchovy, and deepbody anchovy came in as adults during the wet years and successfully spawned. Other native estuarine species entered during wet years as juveniles, survived and often were trapped if the lagoon remained closed, including California killifish, staghorn sculpin, arrow goby, longjaw mud-sucker, and striped mullet. They were only rarely encountered as surviving adults under closed conditions. They reproduce in tidal estuaries or marine environments and only the California killifish reproduced in the lagoon based on about 10 small juveniles (10-20 m SL) taken on 23 June 2000 after the lagoon had been closed for at least a month. Otherwise California killifish were rare and usually only present during or soon after the lagoon had been open. Two adult California killifish recorded on 14 October 1993 in a long-closed lagoon were seen snorkeling and not taken in seine hauls. Twice in mid-May, 2005, eight reef surfperch, *Micrometrus aurora*, were taken in the lower lagoon during an open period and undoubtedly strayed from the rocky and cobble intertidal habitat off the mouth of the lagoon. Small juveniles of the non-native estuarine species, the yellowfin goby, *Acanthogobius flavimanus*, also were taken during some open lagoon periods (5) and one large adult was taken from the long-closed lagoon.

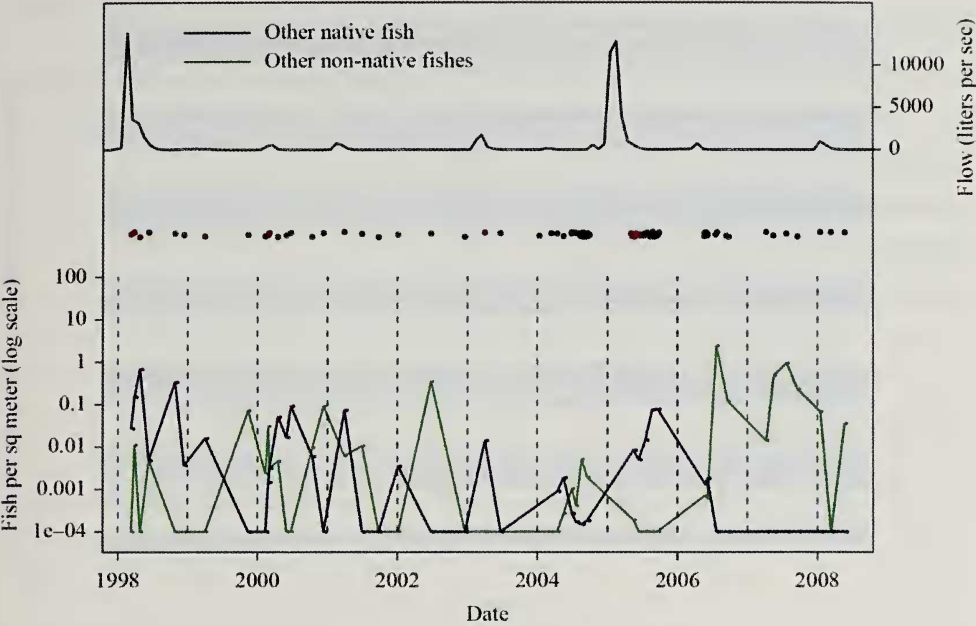


Fig. 9. Abundance of native and non-native species at San Mateo Lagoon, 1998-2008 excluding the southern tidewater goby (native) and mosquitofish (non-native). Dotted vertical lines represent January 1<sup>st</sup> of each year.

Four non-native freshwater fish species came down to the lagoon during the two high rainfall periods, largemouth bass, green sunfish, bluegill, and black bullhead. Largemouth bass reproduced and proliferated in the lagoon in 1998-99 and were extirpated with seines while southern tidewater gobies were absent. One adult bluegill was taken on March 30, 2001 near the lagoon-stream interface. The black bullhead and green sunfish came down both times and remained uncommon or absent from 1998 to 2004. From 2004-2008 green sunfish and black bullhead slowly increased in numbers with successive dry years and became abundant through the end of the study in 2008.

Cluster analysis on the number and presence/absence of the 12 most common species (excluding longjaw mudsucker, bluegill, reef surfperch, arrow goby, and yellowfin goby) resulted in two groups (Fig. 10). One group is a stepwise series of nested associations largely dictated by the relative frequency of the species in all samples. The second group is the strong association of southern tidewater goby and mosquitofish, the two species most abundant and consistently present in both wet and dry seasons. Additional clusters (not shown) utilizing all species (including the rare ones) as well as separating the data into two-time periods bracketing the separate high flow events with slightly different species compositions (1998-2003; 2004-2008) also resulted in similar dichotomies; the southern tidewater goby and mosquitofish strongly associated and separate from the remaining estuarine and freshwater species prevalent during wet seasons. In both time periods the wet season/lagoon opening periods include both the invading estuarine species and freshwater species from upstream. During the intervening dry years, the estuarine species declined or disappeared and the southern tidewater goby, mosquitofish and, from 2004-2008, two non-native freshwater species, green sunfish and black bullhead, proliferated.

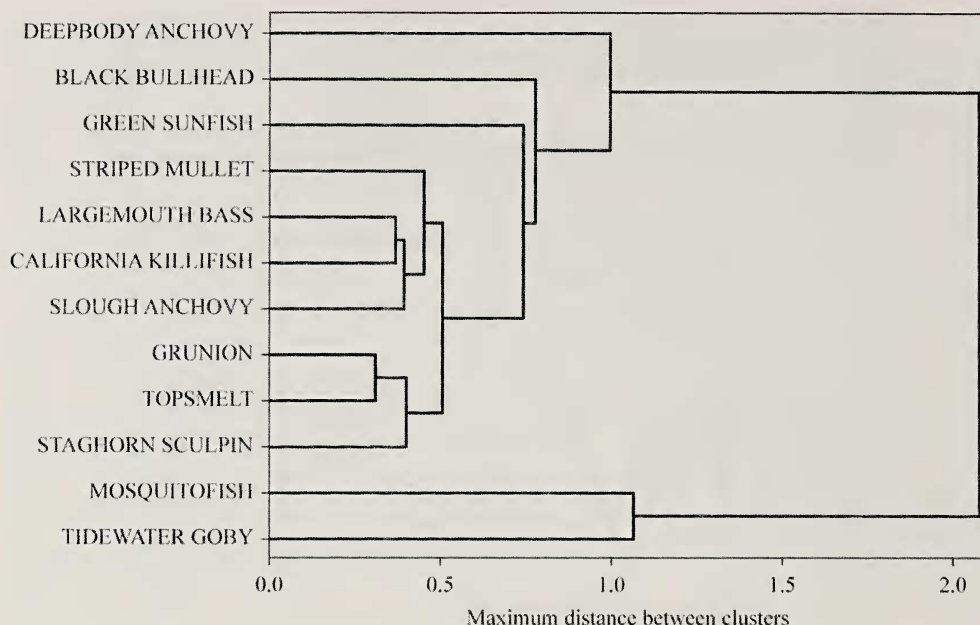


Fig. 10. Cluster analysis with hierarchical clustering with complete linkage of the fish species collected in seine samples, excluding five rarest species (see text).

Two other non-native aquatic species, bullfrog, *Rana catesbiana* and red swamp crayfish, *Procambarus clarki*, were common at the beginning of the study and were decimated during the high 1998 El Niño flows. They increased in abundance through 2004 when active removal efforts began. Catches of both species declined through 2008; the bullfrogs were essentially eliminated but crayfish remained in lower numbers.<sup>1,2</sup>

The 100-200 m of perennial tributary upstream of the lagoon usually supported large numbers of juvenile southern tidewater goby and mosquitofish and fewer green sunfish and black bullhead. On November 26-27, 2001 the removal effort took 1648 juvenile to adult southern tidewater gobies (about 14.5 gobies/m<sup>2</sup>) and a few hundred each of mosquitofish and red swamp crayfish. On 8 February 2002 124 southern tidewater gobies came from 93 m of the new channel with about the same number of mosquitofish crayfish.

### Discussion

When open the lagoon became at least partially tidal. Deep initial gaps scoured through the sand berm usually lasted only days during peak flows and the bar quickly began to reform. Surf action kept the breach in the barrier sand bar relatively high and shallow, muting the tidal fluctuation. Tidal influence progressively became restricted to the periods of highest spring tides in the middle of the night about every two weeks (grunion tides). At lower

<sup>1</sup> ENTRIX, Inc. 2007. Results of exotic predator removal efforts from San Mateo Lagoon and creek from 9 April to 20 September 2007. Report for CalTrans via EDAW, Inc., San Diego, Project Number 3049906, 23 pp.

<sup>2</sup> ENTRIX, Inc. 2008. Final Report. Results of exotic predator removal efforts in San Mateo Creek and lagoon between 16 January to 23 May 2008. Report for Caltrans via EDAW, Inc., San Diego, Project Number 3049908, 44 pp.

tides the lagoon stabilized with little or no outward flow and some seepage through the berm. After complete closure, the lagoon level became elevated a meter or so above mean high tides. Marine water occasionally washed into the lagoon through the lower level of the sand berm at the former outlet when high surf occurred during nocturnal highest tides. The progressively widening of the barrier berm into the summer reduced the ability of waves to wash over and the lagoon level stabilized about a meter or more above mean high tide. Some seepage through the barrier sand bar and evaporation contributed to the lagoon level slowly declining during the dry season or over successive dry years. The lagoon was reduced to one hectare or less by 2008 and was observed by Swift and Holland to become reduced in size also by the early 1990s after the dry period spanning the late 1980s and early 1990s.

Estuarine coastal lagoons or estuaries that close to the ocean to some extent have recently been labelled variously as: 1) temporary open/closed estuaries (TOCE) (Whitfield et al. 2012; Collins and Melak 2014); 2) intermittently open/closed estuaries (IOCE) (McSweeney et al. 2017); 3) intermittently closed and open lakes or lagoons (ICOLL) (Sadat-Noori et al. 2016); or, 4) intermittently closed estuaries (ICE) (Moreira et al. 2015) and are prevalent in coastal areas with Mediterranean climate regimes like the west coast of North America. Jacobs et al.'s (2011) historical research and classification of these systems in southern California concluded that only a few of the largest California estuaries like San Diego and San Francisco bays were consistently open to the sea. As we have observed and Jacobs et al. (2011) determined San Mateo Lagoon is a highly enclosed system perched above high high tide as the predominant condition on a terraced coastline facing southwesterly and exposed to southerly and El Niño storms on an isolated medium-sized coastal drainage. This places it at the largely closed, fresh or brackish water end of a spectrum that extends to systems rarely or never completely closed with strong marine or saline influence. However, as we have observed, San Mateo Lagoon transitions over a few weeks or months from a marine influenced system to its "predominant" closed and fresh or brackish condition during wet years. Artificial modifications and development has converted many systems that were similar to San Mateo farther towards increased tidal and marine conditions. Unlike many other sites closely fringed with development, San Mateo Lagoon currently has relatively unfettered ability to expand inland with sea level rise, an accommodation not available at many other sites.

The geographical location of the lagoon in the coastal belt of summer fog makes the highest local air temperatures often in spring and fall when more sunlight is present (Leighly 1934; Patton 1956; Purer 1942). This depression of summer air temperatures often does not show up in the typically averaged monthly air temperature data. The summer fogs diminish summer solar impacts, which are stronger in fall and spring and combine to make the water temperature often cooler than the local ocean in summer and warmer than the ocean in the winter. The lagoon water temperature often varies less than in the nearby marine environment when lagoons are closed or nearly so. Sudden cooling can occur in winter when the lagoon opens to the colder ocean simultaneously with incoming stream flows cooled by exceptionally cold air.

The water temperature records at San Mateo did not show any reduction in mid-summer as documented in the more tidal Ballona Marsh.<sup>3</sup> At San Mateo water

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<sup>3</sup> Swift, C.C. and G.D. Frantz. 1981. Estuarine fish communities of Ballona. 31 pp. in *Biota of the Ballona Region Los Angeles County* (R. Schrieber, ed.), Natural History Museum of Los Angeles County, Los Angeles.

temperature rose to the low to mid-20's C in mid to late summer and the two to four values measured from the lower and upper lagoon and creek usually differed less than 3-5° C from each other. Still some shaded areas of the lagoon under the railroad trestle remained cooler, i.e. in the lower rather than mid-20's C. The creek temperatures were similar to the lagoon in the early years of the study since the riparian vegetation had been removed and exposed the creek. In later years as the riparian vegetation redeveloped the ground water fed creek was several degrees cooler in the summer rarely above 20° C (Fig. 7).

The fluctuations of fish populations at San Mateo Lagoon corresponded to the cycles of two near record wet periods separated by stretches of near record dry years. Wet years opened the lagoon and allowed native estuarine species to enter from the ocean like topmelt and the two species of anchovies that spawned in the lagoon. Large numbers of adult grunion occasionally were trapped in the lagoon after washing in during nocturnal high tides in spring. They feebly swam at the surface near the seaward end of the lagoon, apparently stressed by low salinity exposing them to predation by larger tern species. Four other estuarine fish species entered as larvae or small juveniles and did not reproduce, longjaw mudsucker, striped mullet, staghorn sculpin, and arrow goby. A ninth species, california killifish, typically inhabit more tidal estuaries and occur sparsely along sandy coasts. They invaded the lagoon and even reproduced on one occasion. The surfperch rarely strayed into the lagoon from the rocky substrate just off the mouth of the lagoon. All of these disappeared or remained as rare adults during intervening dry periods. The southern tidewater goby was the only native species that maintained large numbers during the dry periods when the lagoon was mostly closed or opened only briefly.

Non-native species also increased with the wet years with the yellowfin goby entering as small juveniles during lagoon opening but only surviving as a handful of adults in the closed lagoon after the 2005 wet year. Green sunfish, largemouth bass, and black bullhead came down from upstream during the first wet season and the sunfish and bullhead only were recorded during the second. They remained rare after 1998 probably because the lagoon was strongly flushed out in early 1998 and lacked vegetative cover. Also, in early 2000 the smaller lagoon experienced an artificial opening and resulting high salinity event that was probably detrimental to them. After 2005 the green sunfish and black bullhead increased in numbers through 2008 despite efforts to remove them. The lagoon retained considerably marginal emergent vegetation providing cover for these two species. The many juvenile largemouth bass present in the latest 1990s were removed successfully by the time southern tidewater gobies were re-introduced in January 2000. Predation by the increased number of sunfish and bullhead catfish almost certainly caused the extirpation of the southern tidewater goby by mid-2007. The larger gobies (longjaw mudsucker, yellowfin goby) and staghorn sculpin could prey on southern tidewater goby but very few survived in the closed fresh or brackish conditions of the closed lagoon. Yellowfin goby and staghorn sculpin live for at least several months in freshwater farther north (Moyle 2002). Our record for large longjaw mudsucker in the lagoon indicate it is equally tolerant despite Barlow's (1961) contention it could survive only about two weeks in fresh water. The one goldfish taken during frog removal efforts was obviously a recent unauthorized release.

In 1996 and 1998-2001 the seven other lagoons to the south on the base were sampled one to four times per year and similar increases in number of fish species were recorded

during the 1998 El Niño.<sup>4,5</sup> Six of these lagoons north to south (San Onofre, Las Flores (Las Pulgas on some maps), Hidden, Aliso, French, and Cockleburrr) were about the same size or smaller than San Mateo, had similar fish faunas, and also lost some of the estuarine species after one or two years. San Onofre and Las Flores with relatively large freshwater input returned to fresh or brackish condition similar to San Mateo. The other four lagoons with smaller drainage basins and reduced freshwater input often retained considerable salinity along with some estuarine species like longjaw mudsucker, staghorn sculpin, arrow goby and few others not recorded in San Mateo like shadow goby, *Quietula y-cauda*, cheekspot goby, *Ilypnus gilberti*, and diamond turbot, *Pleuronichthys guttulatus*. Hidden and French often became hypersaline and French typically dried to a small hypersaline and fishless pool within a salt flat during the stretches of dry years. The much larger and southernmost lagoon on MCB, the Santa Margarita River, usually had all the above species except southern tidewater goby that disappeared in the early 2000s. In addition, grey smoothhound, *Mustelus californicus*, round stingray, *Urobatis halleri*, california butterfly ray, *Gymnura marmorata*, bat ray, *Myliobatis californica*, and the rare southern invader, longtail goby, *Ctenogobius sagittula*, were taken. In 1999 two striped bass, *Morone saxatilis*, were taken during the colder oceanic La Niña conditions that brought an increased notice of catches of this species in the anecdotal angler records in the regional newspaper Western Outdoor News. A small population of another southern estuarine species, the Pacific blue crab, *Callinectes arcuatus*, also was present in the Santa Margarita for about a year and a half in 1998-99, was not seen subsequently, but was again present in January 2009 (Swift, personal observation, LACM specimens). The Pacific blue crab and longtail goby apparently had not been able to establish reproducing populations up through 2009.

Ambrose and Meffert (1999) and Collins and Mellack (2014) extensively describe and compare the patterns of fish community variation in small TOCE's both in southern California and elsewhere in Mediterranean climate regions. Diversity is typically lowest in non-tidal or microtidal systems mostly brackish or freshwater with a few brackish specialists like the southern and northern tidewater gobies in California. Increased tidal action and salinity with rising frequency and depth of openings supports progressively more species and diversity of estuarine and marine species, many using the estuary as a nursery. Some or all of these dominated the fish communities in other more tidal and saline southern California estuaries (Allen et al. 2006) except tidewater gobies and steelhead that have been greatly reduced or extirpated in many of the more saline and tidal systems.

Two additional native fishes, partially armored threespine stickleback, *Gasterosteus aculeatus microcephalus*, (last recorded in 1939) and southern steelhead, *Oncorhynchus mykiss* (Swift et al. 1993; Hovey 2004; Hubbs 1946) previously occurred or traversed San Mateo Lagoon but were not taken in this study. Genetic evidence showed at least 5 steelhead entered San Mateo Creek and spawned upstream in 1998 (Hovey 2004). Their progeny also reproduced in a tributary creek but dry conditions in subsequent years prevented the adults

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<sup>4</sup> Swift, C.C., and D.C. Holland. 1998. The status and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces, Gobiidae), on MCB Camp Pendleton, California. Final Rept., Environmental Security, Marine Corps Base Camp Pendleton, CA Contract No. M0068196T5642, 104 pp.

<sup>5</sup> Holland, D.C., C.C. Swift, and N. Sisk. 2001. Status, distribution, and habitat use of the tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), on MCB Camp Pendleton, California, California 1998-2001. Final Report for AC/S Environmental Security, MCB Camp Pendleton, AS, by Camp Pendleton Amphibian and Reptile Survey, Fallbrook, CA. Contract #M00681-00-P-1347.

from returning to the sea as well as the out migration of their offspring to the ocean. The population declined and disappeared by late 2003 (Hovey 2004). Steelhead utilized seasonally stable, brackish or fresh lagoon, and were commonly fished up to 1930s as "sundowners" in southern California coastal lagoons (Hubbs 1946; R. Croker, letter, quoted in Swift et al. 1993). Studies in central California have shown the value of lagoon habitats in allowing the young steelhead to reach larger sizes increasing their success in returning to spawn after their time in the ocean (Satherwaite et al. 2012). Historically the drainage supported more steelhead during periods of wet years and Rodgers (1889) observations and Woefel's (1991) detailed research show the stream was more consistently present all year in the lowland valley above the lagoon before about 1940. Subsequently the transition from dry farming to irrigated vegetables in the floodplain above the lagoon and other water needs made increased demands on the water table of the alluvial valley and stream flow became much less prevalent. The irrigated farming in the drainage ended in 2001 and may lead to increased water in the stream. Partially armored threespine stickleback were probably also affected by loss of flows in the lower creek as well as by predation by the non-native predatory fish and crayfish.

Tidewater gobies were recorded initially in San Mateo Lagoon 1940 (UMMZ 133246) and next in 1974 (Swift et al. 1989). They could not be detected in the mid to late 1980s (Robert Feldmuth, pers. comm., 23 March 1987<sup>6</sup>; Swift visit, 31 August 1988) a period of extended drought. They were absent in 1991<sup>7</sup> but were present and rare in 1993.<sup>8</sup> They remained present and sometimes abundant until March 1998 when extirpated as noted above. Repeated sampling failed to detect them through late 1999 and after their reintroduction in January 2000 they remained present and often abundant through mid-2007 (Fig. 8, Appendix I). They could no longer be found from mid-2007 through mid-2008, apparently extirpated by increasing numbers of non-native predators (sunfish, bullheads) that proliferated in a closed, freshwater lagoon. They were not recorded again until 2010 (Kevin Lafferty, pers. comm.) apparently naturally recolonized after our sampling through mid-2008.

Northern and southern tidewater gobies are characteristic of coastal lagoons, but where habitat remains suitable and accessible they invade low gradient tributary streams. The 100-200 m of perennial tributary upstream of San Mateo Lagoon usually supported large numbers of juvenile tidewater goby and mosquitofish and fewer green sunfish and black bullhead. Farther south on the base southern tidewater goby ( $\leq 10$ ) were taken up to 3-4 km above the lagoon in the Santa Margarita River on 6-8 June 2000 (Holland, pers. obs.). Large numbers (at least hundreds) of northern tidewater gobies, *Eucyclogobius newberryi*, moved 7-8 km upstream in the Santa Ynez River in the summer and fall, coincident with upstream movement of juvenile staghorn sculpin and starry flounder, *Platichthys stellatus*

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<sup>6</sup> Feldmeth, C.R., D.A. Guthrie, D.L. Soltz, B.A. Prigge, and W.J. Bond. 1987 (April 25). Draft Biological Resources of the San Mateo Creek area, Camp Pendleton. Robert C. Feldmuth and Associates, Ecological Research Services, Claremont, CA, for Natural Resource Office, Camp Pendleton, CA, Contract No. M00681-85-Q-0048, 139 pp.

<sup>7</sup> Holland, D.C. 1992. The distribution and status of the tidewater goby (*Eucyclogobius newberryi*) on Camp Pendleton, San Diego County, California. Environmental and Natural Resources Office, Marine Corps Base Camp Pendleton, California.

<sup>8</sup> Swift, C.C., J.N. Baskin, T.R. Haglund. 1994. The status and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces: Gobiidae), on MCB Camp Pendleton, California. Marine Corps Base Camp Pendleton, Report for Contract # M0068193-P-4385.

in 1995-1997.<sup>9</sup> Tributaries can provide nursery habitat for tidewater gobies where accessible, but today many coastal lagoons have natural or artificial barriers to such movement. Rodgers (1889) observed the San Mateo Valley "...is notable as one of the few through which a well-organized running stream may be seen above the surface, the year round." Possibly this just referred to the lower few hundred meters as we have observed, but the water table was probably higher historically and more consistently supported a surface stream along the 7-8 km of low gradient floodplain upstream of the lagoon (Woefel 1991).

Removal of abundant bullfrog larvae seemed to allow greater growth of green algae in the lagoon, and historically, the larvae of the native and federally threatened California redlegged frog, *Rana aurora draytoni*, now locally extirpated<sup>10</sup> (Jennings and Hayes 1994), may also have reduced the algae. The federally endangered arroyo toad, *Bufo californicus* was present and larvae and small juveniles were present in the upper lagoon during the two wet years. They successfully bred locally during these wet years since the strong flows exposed shallow marginal gravel bars they prefer for breeding. They were not detected in other dryer years in and near the lagoon. The southwestern pond turtle, *Clemmys marmorata*, was present throughout the study.

Bullfrogs and crayfish were reduced by seining and trapping. Local populations of southwestern pond turtles, cormorants, black crowned night herons, great blue herons, great egret, snowy egret, and kingfishers also targeted fish and crayfish in the lagoon. The crayfish declined in numbers, but some remained using the vegetation as a refuge from capture and predation. Bullfrogs adults, larvae, and egg masses were targeted from 2004 to 2008, and were essentially extirpated in the local area.<sup>11,12</sup> Occasional adults taken probably immigrated from adjacent drainages or from upstream areas outside the study area. San Mateo Lagoon is relatively isolated by unsuitable habitat for these two species. Concerted effort on complete drainages followed by continued follow-up could largely eliminate or greatly reduce them in many areas. This effort should be targeted to periods immediately or soon after high flow events when the species have been naturally decimated and the open habitat condition makes the species vulnerable to removal methods. A few ( $\leq 10$ ) red eared sliders, *Trachemys scripta*, were taken in 2004-2008 while trapping for non-native fish and were removed from the lagoon.

Historical maps and accounts of early travelers and residents (Rodgers 1889; Woefel 1991; Engstrom 1999, 2006; Grossinger et al. 2011) indicate a wider and larger San Mateo lagoon extending inside and parallel to the sand dunes before the railroad crossing was built. The lagoon was further restricted in the 1930s when levees were established to protect

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<sup>9</sup> Swift, C.C., P. Duangsitti, C. Clemente, K. Hasserd, and L. Valle. 1997. Biology and distribution of the tidewater goby, *Eucyclogobius newberryi*, on Vandenberg Air Force Base, Santa Barbara County, California. Final Report, U.S. National Biological Survey Cooperative Agreement No.1445-007-94-8129 with Loyola Marymount University, Los Angeles, 121 pp.

<sup>10</sup> Holland, D.C. and R.H. Goodman, Jr. 1998. A guide to the amphibians and reptiles of MCB Camp Pendleton, San Diego County, California. Report for AC/S Environmental Security, Marine Corps Base Camp Pendleton, Contract M00681-94-C-0039, by Camp Pendleton Amphibian and Reptile Survey, Fallbrook, CA, v + 546 pp.

<sup>11</sup> ENTRIX, Inc. 2007. Results of exotic predator removal efforts from San Mateo Lagoon and creek from April 9 to September 20, 2007. Report for CalTrans via EDAW, Inc., San Diego, Project Number 3049906, 23 pp.

<sup>12</sup> ENTRIX, Inc. 2008. Final Report. Results of exotic predator removal efforts in San Mateo Creek and lagoon between January 16 and May 23, 2008. Report for Caltrans via EDAW, Inc., San Diego, Project Number 3049908, 44 pp.

the new Highway 1 bridge (today's Old Road Bridge), deflecting the stream from the marsh towards the larger, northern railroad bridge (Celia Kutcher, pers. comm., 10-14 September 2014, via discussions with Paul Campo of Marine Corps Base, Camp Pendleton in the 1970s). The lagoon is now restricted to a narrower, linear lagoon almost perpendicular to the shore (Fig. 1). The area and volume of the lagoon was considerably larger and high flows were not channeled directly towards the ocean. A wider lagoon and more marginal wetlands were available to absorb higher flows and the breaching or outlet channel would often be diverted southward along the coast by longshore currents and wave action.

The original lagoon would have been shallow (1-2 m) like today because sediments more or less spread evenly across the lagoon. The resistance of lagoon margins causes slightly more scouring such that the lagoons are often 10-20% deeper on the margins than over most of its area away from the banks. A broad shallow configuration allows wind-driven circulation to keep the water column well oxygenated and prevents or minimizes development of deeper pockets that trap saline water. Saline lenses differentially absorb solar radiation becoming warmer and anoxic. These conditions drive intolerant species of fishes, amphibians, reptiles and other organisms out of deeper water into shallows and more vulnerable to predators. Narrowing of the lagoon also inhibits the deflection or migration of the outlet down the coast where the effects of breaching are much less than when a deep opening is directly scoured as an extension of the main channel.

We observed, and the State Park staff and others have related on a few occasions at San Mateo and other coastal lagoons, bullfrog larvae, crayfish, and bullhead catfish have littered the local beaches soon after high flows breach of the lagoon in the wet season. The native southwestern pond turtles often get washed out as well. During a similar even on nearby San Onofre Lagoon we observed gulls picking up bullfrog larvae but losing interest soon after apparently due to their toxic skin. The high salinity along the beach leads to extensive mortality of these freshwater species. The pond turtles and crayfish crawl out of the surf back towards the lagoon, but some beach goers, believing these are young lobsters and sea turtles, attempt to return them to the ocean. During the strong opening and mixing of fresh and saline water in the lower lagoon 17 May-16 June 2005 10-20 moribund southern tidewater gobies and windrows of dead aquatic insects were present along the lower lagoon. Swift et al. (1989) showed southern tidewater goby, while tolerant of a wide range of salinity, had more difficulty adapting to rapid, strong changes in salinity.

In addition to these natural winter breaching events, mortality of native and non-native aquatic species can result from a sudden, artificial breaching of a lagoon in the dry season (Swift, et al., pers. obs.). Periodic dry season opening of the lagoon for public health reasons, along with the lagoon at San Juan Creek to the north, began when the State Park was established in 1971 (C. Kutcher, personal communication, see above) but was later curtailed to protect the native aquatic species. Some surfers believe opening lagoons provides a fresh sand deposition just offshore enhancing the surf break at this famous surfing beach ("Upper trestles"). These artificial breaches are timed with extreme low tides to maximize the draining and sediment movement. This also maximizes the effects on lagoon inhabitants when there is little or no freshwater inflow to refill the lagoon. Sometimes summer openings are made to remove pollution, excess algae build up, or perceived adverse odors but then can add to the bacterial count in local beach water. Farther north coastal lagoons have been breached to facilitate entry of anadromous salmonids in the fall or winter before natural openings occur. The lowering of lagoon levels whether natural or artificial often forces fishes and other organisms out of marginal protective vegetation.

Changes in the vegetative cover affected the survival of fish populations. Sudden lowering of water levels exposes fish to predation since they lose access to marginal vegetative cover. During our study this marginal aquatic vegetation also prevented complete control of non-native exotic predators but was beneficial for many native organisms, some now locally extirpated. However, historically Native American populations also impacted this vegetation. In August 1856 while passing by San Mateo Lagoon Hayes (1929: 117) noted "Much of the tule here had been cut by the Indians for their various uses." This portrays a substantial local effect on marsh vegetation that may have been typical for many California coastal marsh habitats every fall, or possibly even more frequently, for the last few thousand years.

### Conclusions

Historically San Mateo lagoon supported more native fishes and amphibians with increased and consistent freshwater inflow and a larger lagoon. Like Ambrose and Meffert (1999) at Malibu Lagoon, our sampling did not take the federally endangered southern steelhead known to have passed through the lagoons in both systems during the studies. Although a small steelhead run remains at least intermittently in both drainages, neither lagoon appears to support southern steelhead recruitment. Both could be restored enough for this function to return. Lagoons may have been relatively more important for steelhead in southern California given the smaller and less persistent freshwater tributaries compared to more northern localities. Such restoration would also benefit threespine stickleback, red-legged frog, arroyo toad, southwestern pond turtle, and southern tidewater goby.

An overall long-term trend of reduction and confinement of coastal lagoons including San Mateo as noted above needs to be reversed to increase the suitability for the suite of native aquatic species. Despite the apparent decrease of freshwater inflow from the creek, San Mateo lagoon stays fresh, brackish, or nearly so most of the time. The lack of dams or other sediment diversions means sediments continue to be delivered to the lagoon providing material for the building of barrier sand berms by coastal wave action. The lagoon should be allowed or restored to a broader footprint closer to its original extent. The elevated railroad berm and the levees confining the channel inhibit natural expansion of the lagoon laterally and also block the more or less continual wind that helps mix and oxygenate the lagoon waters. Confinement into a narrower channel allows high flows to scour deeper channels that inhibit complete wind-driven mixing of the water column as well, making it easier for saline lenses to develop. Channelized high flow place more force directly against the barrier berms increasing the extent and duration of breaches to the ocean instead of dissipating them laterally down coast where outlet channels remain shallower and higher in the tidal range. Such muted breaching allows interchange of fishes but retains more of the lagoon intact in contrast to the more severe direct scouring that can nearly or completely drain the system. Even just seasonal flooding of lateral lagoon margins provides valuable refuge for native fishes during high scouring flows. Restoration of coastal lagoons and their historical fauna and flora will necessitate reversing these trends by reproducing or simulating historical conditions as much as possible. Preventing artificial breaching has been part of such management and educational efforts to discourage, manage or prevent artificial breaching as well as to improve water quality and supply in these coastal habitats should be continued.

Habitat changes must be accompanied by management or removal of exotic competitors and predators that we have seen can thrive under some conditions. Strong

circumstantial evidence indicates steelhead, threespine stickleback, both species of tide-water goby, and small juvenile southwestern pond turtle are negatively impacted by non-native predators, including largemouth bass, sunfish, bullheads, and bullfrogs. Lafferty and Page (1997) showed African clawed frog, *Xenopus laevis*, also preyed on northern tidewater goby in the Santa Clara River estuary. Various life stages of these non-native animals can both prey on native species as well as compete for resources. Red swamp crayfish also have strong effects on amphibian eggs and larvae along with the other non-native species in southern California (Riley et al. 2005). Bullfrogs appear easiest to control at San Mateo because of the vulnerability of the adults and the egg masses. Targeting them led to virtually complete removal save for occasional immigration. The exotic freshwater fish are more difficult once established since they have much inaccessible habitat for protection. Success was achieved with largemouth bass since they were more vulnerable immediately and soon after flood scouring of the lagoon that removed much of their cover. Crayfish removal is much harder to accomplish and with freshwater fishes should probably be concentrated after exceptional flood conditions when they are very reduced as well as identifying upstream sources that can be controlled or removed.

Steelhead can reinvade the San Mateo drainage under favorable conditions, but it is very unlikely stickleback or redlegged frog could naturally recolonize. Like southern tidewater goby they would have to be artificially brought in from the most genetically suitable populations. Normally this would require at least a few hundred individuals to assure genetic viability (USFWS 2005). Such reintroductions should not be carried out until the habitat is considered favorable including the reduction or elimination of the known and suspected incompatible non-natives.

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## Appendix I

Dates, seine hauls, area seined, fish catches and condition of lagoon opening to ocean for San Mateo Lagoon, 1993–2008. Numbers in species columns and total fish column represent actual counted and estimated catches. Columns of both total native and total non-native species include numbers based on multiples indicated in “Multiplier” column for southern tidewater goby and mosquitofish numbers (see Methods).

Date (mm/dd/yr)	Number of hauls	Area m <sup>2</sup>	Multiplier (see text)	Native fishes										Non-native fishes										Total fish	Total native fish	Total non-native fish	Closed (1); open (2)
				Southern Tidewater Goby	Arrow Goby	Longjaw Mudsucker	Staghorn Sculpin	Deepbody Anchovy	Slough Anchovy	California Killifish	Striped Mullet	Topsmelt	Grunion	Reef Surperch	Yellowfin Goby	Mosquitofish	Largemouth Bass	Black Bullhead	Green Sunfish	Bluegill							
10/14/93	24	329	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	326	26	300	1			
10/20/96	16	333	1	1323	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2150	1323	827	1			
03/11/98	15	555	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	0	2			
03/28/98	12	180	1	0	0	0	0	0	0	0	15	0	0	0	0	2	0	0	0	0	29	27	2	2			
04/26/98	20	300	1	0	0	0	0	0	0	0	25	0	0	0	0	204	0	0	0	0	204	204	0	2			
06/11/98	34	1039	1	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	10	5	5	1			
10/27/98	21	783	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	350	264	86	1			
12/12/98	14	548	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	1			
04/02/99	32	877	1	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	14	16	2			
11/13/99	24	1597	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	184	0	184	1			
02/11/00	32	1280	1	5	0	0	0	0	0	0	0	0	0	0	0	6	2	1	0	0	14	5	9	1			
02/26/00	17	680	1	0	0	0	0	0	0	0	1	0	0	0	0	25	2	19	0	0	47	1	46	2			
03/03/00	49	1263	1	3	0	0	0	0	0	0	0	0	0	0	0	1500	1	3	0	0	1511	7	1504	2			
04/17/00	38	1520	1	0	0	0	27	0	0	0	0	10	40	0	0	100	0	7	0	0	184	77	107	2			
05/31/00	24	360	1	101	0	0	6	0	0	0	0	0	0	0	0	1200	0	0	0	0	1307	107	1200	1			
06/23/00	24	360	1	54	0	0	15	0	0	18	0	0	0	0	0	550	0	0	0	0	637	87	550	1			
10/13/00	21	840	1	95	0	0	5	0	0	0	0	0	0	0	0	2500	0	8	0	0	2608	100	2508	1			
12/11/00	19	285	1	323	0	0	0	0	0	0	0	0	0	0	0	1160	0	26	0	0	1509	323	1186	1			
03/30/01	22	330	1	568	0	0	14	0	0	0	10	0	0	0	0	59	0	1	0	1	653	592	61	2			
06/30/01	12	191	1	2158	0	0	0	0	0	0	0	0	0	0	0	410	0	2	0	0	2570	2158	412	1			
09/25/01	19	190	1	1887	0	0	0	0	0	0	0	0	0	0	0	745	0	0	0	0	2632	1887	745	1			
01/04/02	19	285	1	450	0	0	1	0	0	0	0	0	0	0	0	300	0	0	0	0	751	451	300	1			
06/25/02	29	435	1	483	0	0	0	0	0	0	0	0	0	0	0	500	0	150	0	0	1133	483	650	1			
12/19/02	24	588	1	10	0	0	0	0	0	0	0	0	0	0	0	150	0	0	0	0	160	10	150	1			

Date (mm/dd/yr)	Number of hauls	Area m <sup>2</sup>	Multiplier (see text)	Native fishes										Non-native fishes										Total fish	Total native fish	Total non-native fish	Closed (1); open (2)
				Southern Tidewater Goby	Arrow Goby	Longjaw Mudsucker	Staghorn Sculpin	Deepbody Anchovy	Slough Anchovy	California Killifish	Striped Mullet	Topsmelt	Grunion	Reef Surfperch	Yellowfin Goby	Mosquitofish	Largemouth Bass	Black Bullhead	Green Sunfish	Bluegill							
04/02/03	19	285	1	44	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	51	48	3	2		
06/23/03	8	120	1	1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1629	1600	29	1		
01/13/04	13	325	1	92	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	107	92	15	1			
03/15/04	38	1388	2	635	0	0	2	0	0	0	0	0	0	0	595	0	0	0	0	0	1232	1272	1190	1			
04/14/04	36	1124	1	2474	0	0	1	0	0	0	0	0	0	0	2093	0	0	0	0	0	4568	2475	2093	1			
05/17/04	41	3728	7	1176	0	0	7	0	0	0	0	0	0	0	1	469	0	0	0	0	1653	8239	3284	1			
06/28/04	15	225	1	2625	0	0	0	0	0	0	0	0	0	0	1	450	0	0	0	0	3076	2625	451	1			
06/30/04	29	4191	2	600	0	0	3	0	0	0	0	0	0	0	1	342	0	0	0	0	946	1203	685	1			
07/14/04	17	1640	9	300	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	304	2700	28	1			
07/19/04	19	2070	9	51	0	0	1	0	0	0	0	0	0	0	0	60	0	0	0	0	112	460	540	1			
07/29/04	18	1844	7	70	0	0	0	0	0	0	0	0	0	0	0	378	0	2	0	0	450	490	2648	1			
08/04/04	46	1448	5	124	0	0	0	0	0	0	0	0	0	0	0	4864	0	4	0	0	4992	620	24324	1			
08/12/04	12	1968	9	1	0	0	0	0	0	0	0	0	0	0	19	0	15	0	0	35	9	186	1				
08/18/04	13	1440	9	27	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	47	243	180	1				
08/23/04	13	1440	9	15	0	0	0	0	0	0	0	0	0	0	34	0	15	0	0	64	135	321	1				
08/25/04	14	1580	9	17	0	0	0	0	0	0	0	0	0	0	26	0	40	0	0	83	153	274	1				
08/31/04	17	1880	9	79	0	0	2	0	0	0	0	0	0	0	45	0	60	0	0	186	713	465	1				
09/02/04	15	3220	9	59	0	0	0	0	0	0	0	0	0	0	14	0	45	0	0	118	531	171	1				
09/07/04	16	2364	1	50	0	0	1	0	0	0	0	0	0	0	21	0	20	0	0	93	51	42	1				
09/09/04	13	1244	9	20	0	0	0	0	0	0	0	0	0	0	26	0	15	0	0	61	180	249	1				
09/14/04	17	1580	9	13	0	1	0	0	0	0	0	0	0	0	40	0	20	0	0	74	118	380	1				
09/21/04	16	2095	9	32	0	0	0	0	0	0	0	0	0	0	18	0	20	0	0	70	288	182	1				
09/23/04	15	3555	9	28	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	51	252	207	1				

Date (mm/dd/yr)	Number of hauls	Area m <sup>2</sup>	Multiplier (see text)	Native fishes										Non-native fishes							Total fish	Total native fish	Total non-native fish	Closed (1); open (2)
				Southern Tidewater Goby	Arrow Goby	Longjaw Mudsucker	Staghorn Sculpin	Deepbody Anchovy	Slough Anchovy	California Killifish	Striped Mullet	Topsmelt	Grunion	Reef Surperch	Yellowfin Goby	Mosquitofish	Largemouth Bass	Black Bullhead	Green Sunfish	Bluegill				
09/28/04	19	2290	9	142	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	171	1279	252	1
09/30/04	20	2420	9	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	657	315	1
05/05/05	28	1176	1	98	0	0	25	1	0	0	0	0	0	0	0	0	0	0	0	0	128	124	4	2
05/12/05	46	1932	9	26	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	31	237	10	2
05/17/05	38	1596	9	105	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	113	953	0	2
05/18/05	49	2058	9	8	0	0	2	16	0	0	0	1	0	0	0	0	0	0	0	0	33	97	0	2
05/23/05	30	1260	9	1	0	0	0	2	0	0	0	13	0	2	0	0	0	0	0	0	18	26	0	2
05/24/05	46	1932	9	13	0	0	0	15	0	0	0	8	0	0	0	0	0	0	0	0	36	140	0	2
06/01/05	38	1596	9	10	0	0	1	40	0	3	0	0	1	0	0	1	0	0	0	0	56	135	9	2
06/16/05	27	1134	9	2	0	0	1	32	0	0	0	15	0	0	0	0	0	0	0	0	52	66	18	2
06/20/05	30	1260	9	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	6	27	27	2
07/11/05	26	1092	9	8	0	0	1	4	0	0	0	4	0	0	0	4	0	0	0	0	21	81	36	1
07/13/05	41	1722	9	3	0	0	0	15	0	0	0	2	0	0	0	2	0	0	0	0	22	44	18	1
07/27/05	30	1260	9	11	0	0	4	36	0	4	0	1	0	0	0	29	0	0	0	0	85	144	261	1
08/11/05	35	1470	9	19	0	0	1	128	0	3	0	0	0	0	0	112	0	0	0	0	263	303	1008	1
08/25/05	28	1176	9	51	0	0	0	147	0	3	0	0	0	0	0	127	0	0	0	0	328	609	1143	1
08/30/05	33	1386	9	10	0	0	0	49	0	0	0	0	0	0	0	24	0	0	0	0	83	139	216	1
09/09/05	40	1680	5	215	0	0	1	212	0	0	0	1	0	0	0	669	0	0	0	0	1098	1289	3345	1
09/20/05	46	1932	5	15	0	0	0	87	0	10	0	0	0	0	0	976	0	0	0	0	1088	172	4880	1
09/27/05	45	1890	4	95	0	0	0	138	0	0	0	0	0	0	0	904	0	0	0	0	1137	518	3616	1
05/22/06	26	908	8	33	0	0	5	0	0	0	0	2	195	0	0	16	0	0	0	0	251	466	128	1
05/23/06	49	1243	9	259	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	290	2331	279	1
05/31/06	21	83	1	202	0	0	0	0	0	0	0	0	0	0	0	151	0	3	0	0	356	202	154	1
06/05/06	23	140	1	516	0	0	0	0	0	0	0	0	0	0	0	186	0	1	2	0	705	516	189	1

Date (mm/dd/yr)	Number of hauls	Area m <sup>2</sup>	Multiplier (see text)	Native fishes										Non-native fishes								Total fish	Total native fish	Total non-native fish	Closed (1); open (2)
				Southern Tidewater Goby	Arrow Goby	Longjaw Mudsucker	Staghorn Sculpin	Deepbody Anchovy	Slough Anchovy	California Killifish	Striped Mullet	Topsmelt	Grunion	Reef Surperch	Yellowfin Goby	Mosquitofish	Largemouth Bass	Black Bullhead	Green Sunfish	Bluegill					
06/06/06	12	502	9	2300	0	0	3	0	0	0	1	0	0	0	0	59	0	0	0	0	0	2373	20714	531	1
06/07/06	8	480	9	25	0	0	1	0	0	0	0	0	0	0	0	11	0	0	0	0	0	37	226	99	1
07/19/06	11	440	1	143	0	0	0	0	0	0	0	0	0	0	0	1325	0	502	167	0	0	2137	143	1994	1
07/27/06	4	65	1	43	0	0	0	0	0	0	0	0	0	0	0	900	0	110	130	0	0	1183	43	1140	1
09/13/06	5	300	9	100	0	0	0	0	0	0	0	0	0	0	0	200	0	0	25	0	0	325	900	1825	1
09/26/06	9	90	1	300	0	0	0	0	0	0	0	0	0	0	0	200	0	0	15	0	0	515	300	215	1
04/09/07	18	360	9	30	0	0	0	0	0	0	0	0	0	0	0	31	0	0	5	0	0	66	270	284	1
05/18/07	24	240	9	3	0	0	0	0	0	0	0	0	0	0	0	313	0	0	114	0	0	430	27	2931	1
07/24/07	27	270	1	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0	250	0	0	500	0	500	1
09/20/07	29	290	1	0	0	0	0	0	0	0	0	0	0	0	0	252	0	0	65	0	0	317	0	317	1
01/16/08	15	225	1	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	15	0	0	25	0	25	1
03/12/08	7	350	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
05/22/08	20	200	1	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	7	0	0	30	0	30	1
				22,478	14	2	140	922	261	51	264	62	246	8	6	26,966	122	1096	796	1		53,435			